Nearly 100 years after the Wright Brothers made their famous flight over Kill Devil Hills, North Carolina continues to be an incubator for airborne innovation. Even now, the state is hosting pioneers in aerial data acquisition as it teams with FEMA to tackle the largest LIDAR floodplain mapping project ever conducted.

Courtesy of 3Di

Floodplain Fliers
North Carolina's Massive LIDAR Project

Brandon R. Smith

The eyes of the U.S. mapping community are focused on North Carolina as it embarks on one of the most ambitious floodplain mapping projects ever undertaken by an individual state. The project is attracting attention because of both its cartographic and political significance.

From a mapping perspective, the project, which began in January 2001, is daunting — 48,700 square miles mapped with a vertical accuracy of 20–25 centimeters in less than five years. The results will be served up in standard hardcopy and digital formats via the Internet. The total expenditure is expected to reach $65 million.

Two prime contractors are managing the mapping and flood modeling portions of the project. Both are using airborne LIDAR technology, making this the largest LIDAR mapping project ever attempted.

Politically, the project signals a dramatic shift in floodplain mapping activities away from the federal government and toward the states. But nobody is complaining. The endeavor is clearly a win–win situation

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for the state, FEMA, and most importantly, North Carolina residents.

Good maps save lives & money

Based on experiences cleaning up flood damage from recent hurricanes, North Carolina calculated that such damage costs the state $56 million for every year it doesn't have accurate, up-to-date flood maps. For

FEMA and CTPs Modernize Floodplain Maps

In 1997, FEMA initiated a plan to modernize the U.S. floodplain maps that are used to determine flood insurance rates, mitigate flood disasters, and organize relief efforts. The plan called for converting 74,000 maps to digital formats, updating another 17,500 inadequate maps, and creating nearly 14,000 maps for areas not previously surveyed.

FEMA designed a seven-year modernization program that included using new remote sensing techniques, such as LIDAR and Interferometric Synthetic Aperture Radar, to accelerate the mapping and improve overall accuracy. If carried out, the agency estimates the plan would save $26 billion in flood damage to buildings during the next 50 years.

In fiscal year 2000, however, Congress authorized only $82.7 million for the program compared with the $191.3 million needed to conduct it as planned.

To facilitate and supplement the program, FEMA devised the CTP initiative, which invites local commu-

Dave Saville, FEMA News Photo

Flood damage from recent hurricanes such as Hurricane Floyd (below), which rolled ashore in 1999 have cost North Carolina residents millions of dollar. State and FEMA officials agree that a great deal of property loss might be prevented in the future if flood maps are accurate and remain up-to-date. Such maps could help the state manage development in flood zones as well as create hazard mitigation plans.

Image courtesy NOAA

every dollar spent on mapping, the payback is $3.50.

FEMA, which has traditionally been responsible for mapping floodplains nationwide and producing DFIRMs, sees tremendous benefits in sharing mapping duties and expects this to be the first of many tasks initiated by states. DFIRMs help insurance companies to establish flood insurance rates, state and local governments to determine where new buildings can or cannot be constructed, and the Army Corps of Engineers to design the placement of new dams and levees.

nities, counties, and states to take an active role in assisting with floodplain mapping. Under this approach, $2.40 worth of updated flood maps are produced for every $1 spent by FEMA.

North Carolina is the only state to join FEMA as a CTP, and is therefore the largest participant in the program. The $23 million budgeted by the state for the first year of its program nearly matches FEMA's expenditure on flood mapping for the entire country. Most other CTPs are cities, counties, and river drainage authorities.

Benefits to CTPs are many, but the most important is the merging of local flood knowledge with FEMA's mapping expertise to create superior maps that will save lives and reduce disaster costs. In addition, CTPs accelerate FEMA mapping activities in their areas by partnering with the federal government. FEMA also provides extensive training and technical assistance to CTPs.

Full details on becoming a CTP are available online at www.fema.gov/mit/tsd/CTP_main.htm.

"FEMA has a very limited budget and by having states contribute to the mapping process, we can get a lot more mapping completed than we would otherwise," said Laura Algeo, civil engineer in FEMA Region 4.

The project is an official partnership between FEMA and the state, with North Carolina receiving CTP status (see "FEMA and CTPs Modernize Floodplain Maps" sidebar). As such, North Carolina is responsible for collecting and preparing the DFIRM map data and serving it by way of the Internet, while FEMA manages quality control and will print the hardcopy maps.

Within the state, the Department of Crime Control and Public Safety's Division of Emergency Management oversees the project, with substantial support from four state offices — CGIA, Geodetic Survey, Mitigation Division, and the Floodplain Mapping Program Office.

Inspired by the past

In the past, major hurricanes have produced devastating flooding in North Carolina, among the worst being Hurricane Floyd in September 1999. Fifty-six people were killed along the U.S. East Coast, most by flood waters in eastern North Carolina, and tens of thousands were left homeless after their houses were completely destroyed.

Almost three years later, the state was still rebuilding from the storm, with FEMA continuing to process and pay claims. When the cleanup is finally completed, the total expenditure on Floyd recovery in North

Glossary

CGIA: Center for Geographic Information and Analysis

CTP: Cooperative technical partners

DEM: Digital elevation model

DFIRM: Digital flood insurance rate maps

FEMA: Federal Emergency Management Agency

IMU: Inertial measurement unit

LIDAR: Light detection and ranging

USGS: U.S. Geological Survey
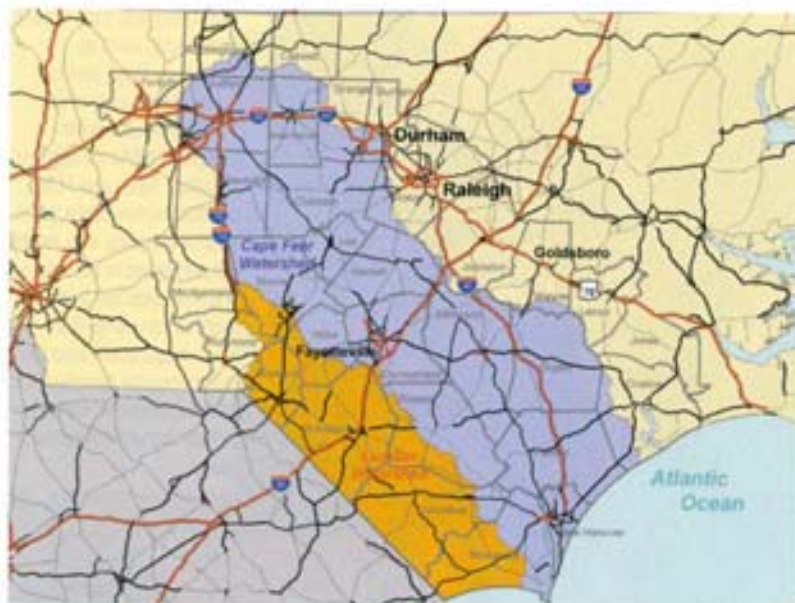
FIGURE 1 During phase 1 of data acquisition, the mapping firms focused on the Cape Fear and Lumber River basins — ground zero for Hurricane Floyd.

LIDAR at Home in the Floodplain

LIDAR is ideally suited for mapping the subtle terrain in floodplains because it directly measures z values, or elevation, very accurately with an extremely high density of points.

LIDAR uses lasers to emit light pulses that strike the ground and reflect back to the sensor. With the precise altitude and position of the aircraft known, the airborne sensor determines the elevation above sea level of each surface point based on the time required for the signal to reflect and return.

For the Lumber River acquisition, the subcontractor deployed four LIDAR systems to handle the 2001 portion of the North Carolina floodplain mapping. Operating at rates between 4,000 and 35,000 pulses per second, these systems measure elevation values for nearly 250,000 points per square mile, or one every 4–5 meters.

Flying in half-mile swaths, each apparatus covered about 120 square miles per day. The accuracy of the collected elevation data easily satisfied FEMA's specifications of 20 centimeters (root mean square error) in coastal areas and 25 centimeters inland.

The systems deployed in North Carolina each contained LIDAR sensors integrated with a GPS receiver and IMU in the aircraft. The IMU provided the precise aircraft and sensor attitude (pitch, roll, and yaw) while the GPS acquired the x, y and z location points of the aircraft.

The LIDAR ground crew used a GPS base station to provide the necessary ground benchmark required to differentially correct the onboard readings to extremely high levels of accuracy and precision. One of the advantages of LIDAR mapping is that no surface features must be marked and surveyed as ground control when differential GPS is in use, thereby reducing field time and expense.

vegetative growth, and alterations in stream channels can dramatically affect the path and volume of water flow during a flood event, thus changing the shape and size of a flood zone over time.

Accurate maps that are kept updated, on the other hand, offer numerous benefits that translate directly into savings of lives and money. The first advantage is prevention — communities use the flood maps to establish zoning regulations that restrict building in flood-prone areas or require special construction measures for structures that are put there.

"Even if houses already are built in the floodplain, the maps still provide benefits," explained Gavin Smith, Mitigation Section Chief in the North Carolina Division of Emergency Management. "The maps inform the public of the risks of living in a flood zone and alert them to the fact they should buy flood insurance."

For towns and cities where development has already spread to the flood zones, North Carolina plans to use its new maps to make communities safer. In some cases, the state will purchase houses in the most high-risk areas and remove them from the floodplain. Other homes and buildings will be raised above the high-water mark.

"These new flood maps will serve as the basis for our hazard mitigation plans, which are now required by the federal government for a state to receive post-disaster funding," said Smith.

North Carolina understands that maps won't prevent a hurricane from hitting, but the mitigation plans created from them will better equip communities to deal with an emergency by designating safe evacuation routes and targeting relief in areas that will be the most inundated.

LIDAR floods in

Because of the immense size of the project area, the Floodplain Mapping Program Office selected two prime contractors to each map half the state with airborne LIDAR. In phase one, a Raleigh, North Carolina–based firm is mapping the Cape Fear and Lumber River basins in southeastern North Carolina — ground zero for the Hurricane Floyd strike (see Figure 1). This portion of the project alone involves developing floodplain delineations across more than 12,000 square miles of drainage area.

Given the large coverage area, short schedule, and high accuracy requirements, LIDAR seemed the logical technology choice.

Airborne LIDAR is well-suited for mapping floodplains for a number of reasons (see "LIDAR at Home in the Floodplain" sidebar). First, LIDAR uses a laser to reflect pulses of light off the ground surface, at rates as fast as 35,000 pulses per second, measuring the position and elevation of each point where light pulses hit, to within centimeters of accuracy. LIDAR can

Carolina is expected to reach $6 billion, split between FEMA and the state.

State and federal officials agree that a lot of the devastation in eastern North Carolina could have been avoided if there had been more accurate DFIRMs. According to FEMA, 55 percent of its flood maps are 10 years old, and many of those were made with USGS data having error rates as large as 25 feet.

Of all map types, flood maps are the most dangerous when out of date because the floodplain is such a dynamic environment. Humanmade construction,

meet North Carolina's requested accuracy standards of 20 centimeters along the coast and 25 centimeters inland.

Another advantage is that in just a few seconds an airborne laser acquires actual measurements, not interpolations, for thousands of points spaced less than 5 meters apart. In addition, because LIDAR systems can be operated in any light conditions, they are insensitive to shadows, sun angle, and darkness. This allows for map data collection from early morning through dark.

These characteristics provide flexibility in acquisition schedules that saves time and money. In phase one, the team was collecting topographic map data for as many as 120 square miles per day, an impossible schedule for other airborne mapping methods.
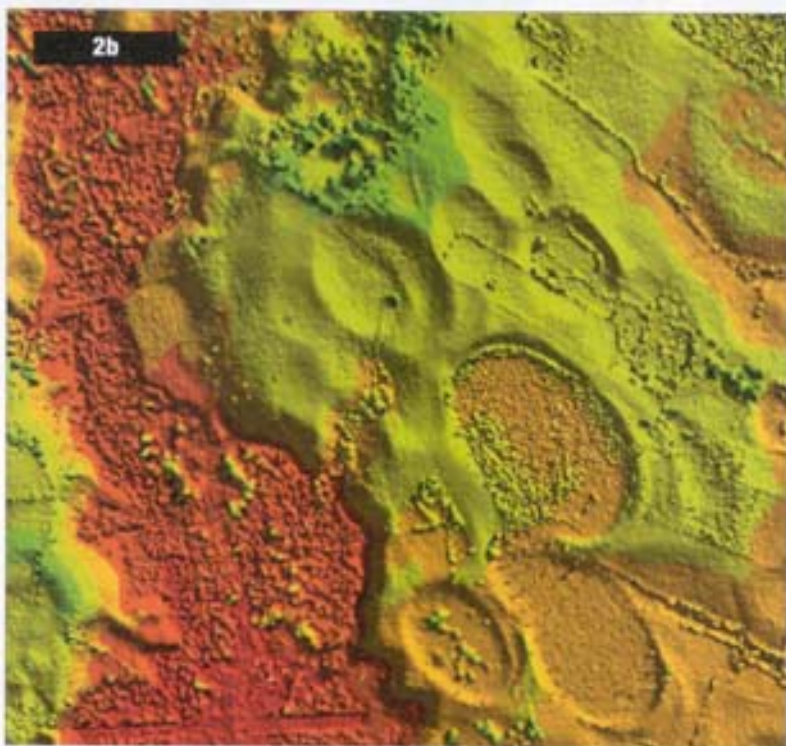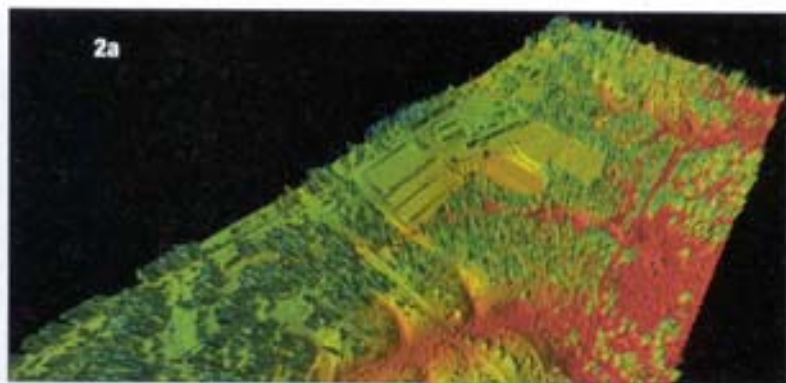
Flying Lumber & Cape Fear basins

In the development of its original proposal drafted in July 2000, the Raleigh contractor tapped a teaming partner to perform the LIDAR data collection. The partner immediately assembled a squadron of four aircraft equipped with LIDAR systems and began acquiring data in January 2001 to take advantage of the winter leaf-off conditions.

A significant benefit of LIDAR mapping to North Carolina, in particular, is its ability to map in vegetative conditions. Although the flying is occurring during leaf-off periods, conifers dominate much of the coastal landscape. But with a bit of ingenuity, one of the mapping subcontractors modified the laser light pulses to measure terrain through and around the trees to return a dataset capable of producing a bare earth DEM, the primary data used in floodplain modeling.

Coastal areas were flown first because leaves appear earlier there, and then the mapping moved progressively inland through winter and early spring, attempting to stay ahead of the foliage.

The biggest challenge faced in this portion of the project was dealing with the pine plantations. In many places, the mature trees are so close together that laser penetration is difficult. The firm overcame this challenge by assigning the pine plantation areas to two LIDAR systems that operate at extremely high pulse rates, between 25,000 and 35,000 pulses per second. This enabled them to collect a greater density of points per square mile, thereby increasing their ability to transmit a laser pulse through the closely spaced trees.

As prioritized by the state, the firm collected data of the Lumber River basin first so that its data could be completed and available for the upcoming hurricane season. Data acquisition of both the Lumber and Cape Fear basins were completed within three months. The firms processed the collected data (nearly 12,000 square miles of terrain) to generate bare earth DEMs (see Figures 2a, 2b, and 2c). These have been com-

pleted and accepted for the Lumber basin and will be delivered as soon as the North Carolina database comes online, probably in early February 2002. DEMs for the Cape Fear basin continue to be processed.

On the ground

Throughout the airborne portion of the project, field surveyors also used GPS in the basins to take cross-section measurements. The goal was to determine distances across the channel from bank to bank and down from the water surface to the river or stream bottoms.

At numerous locations throughout each basin, these crews mapped cross sections by taking GPS points every few feet beginning about 50 feet from the top of the bank and proceeding over the bank and down to the water's edge. This was repeated on both sides of the river. In shallow areas, crews took boats onto the river and used measuring poles to determine where
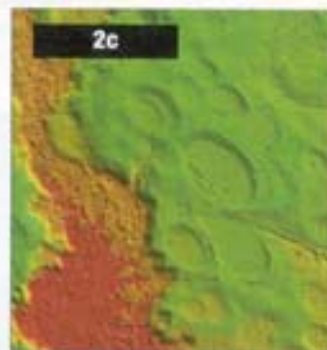

FIGURE 2a and 2b
These DEMs reveal the same reflective surface of LIDAR data in Columbus County before (2a) and after (2b) vegetation data were removed. **Figure 2c** is the final bare earth model of the county.

With input from DEMs, ground-based field data, and predictive rainfall estimates, the engineering firm can calculate magnitude and direction of water flow in flood events. The ultimate goal of the project is to help the state avoid devastating losses such as those sustained by the people of Princeville, North Carolina, during this Tar River flood.

FIGURE 3 After data collection, the mapping team uses a USGS hydrologic model to automatically delineate and display water-surface elevations.

FIGURE 4 One of the main objectives of the project is to update existing flood insurance rate maps and convert them to DFIRMs for the entire state. This must be done in accordance with FEMA standards and specifications.

the bottom lay at points across the channel. For deeper parts near the river mouth, sonar equipment was deployed in boats to capture water-depth readings.

Community involvement also played a key role in field data collection. The Division of Emergency Management conducted multiple interviews with city and town leaders across the state to learn where the most flood-prone areas are and which streams crest the quickest. This insight was used to help focus field surveying in regions of greatest concern.

The field crews delivered the final channel cross-section data along with the LIDAR DEM files to the hydraulic engineers so they can create a total picture of the hydrology above and below the surface of the water. Field work has been completed in the Lumber River basin and is ongoing in the Cape Fear basin.

Modeling hydrology

As prime contractor, the second major aspect of the Raleigh firm's responsibilities after map data collection is to develop hydraulic and hydrologic models. The engineering analysis and modeling are being performed by the firm's staff along with two nationally recognized water resource engineering firms.

This portion of the project involves the use of the USGS Regression Equation hydrologic model and the HEC-RAS hydraulic engineering program (see Figure 3). With inputs of the DEMs, the channel cross sections, and predictive rainfall estimates, these models calculate the magnitude and direction of water flow during 50-, 100-, and 500-year flood events.

By determining how high flood waters will rise and where the water will go, the models define the boundaries of the floodplains under the three possible flood scenarios. The firm's GIS mapping laboratory then plots these boundaries on recently acquired digital orthophotographs to create the DFIRM. Final deliverables to North Carolina and FEMA include the DFIRMs (see Figure 4), base flood elevation maps, LIDAR DEMs, and the channel cross sections. Many of these data sets have already been supplied to North Carolina for quality checking, and final product delivery will occur when the database comes online.

Distributing maps via the Web

FEMA will print and distribute hard copies of the DFIRMs as they have for decades. But a new era in floodplain mapping will begin when North Carolina, through its CGIA, publishes the DFIRMs, along with other relevant map information via the Internet.

This online resource, which has been named the Floodplain Information Management System, is the first of its kind. Ultimately, totaling 9 TB, the data-

The sooner North Carolina can compile and interpret its floodplain data, the sooner the state can begin implementing management and mitigation policies aimed at avoiding the type of devastation visited on Oak Island, North Carolina when Floyd delivered its hurricane force winds and high tides.

Dave Saville/FEMA News

base will include multiple map layers in addition to the DFIRMs and online GIS functionality. The database that will hold all of this information is now under development with a completion date targeted for February.

"We've sent out a survey to all emergency management agencies across the state to learn what they want from the online system in terms of functionality," said Tim Johnson, CGIA acting director. "We're making sure we build the right system for our folks to use."

The online system will allow state and local officials, as well as members of the public, to log on and examine flood insurance rate maps. They will have the option of overlaying political boundaries, emergency facility maps, transportation routes, and other GIS layers maintained by the state.

"The printed DFIRMs will be used for insurance purposes, while our online versions will be utilized for floodplain management and emergency relief efforts," said Johnson. "In the future, we will add a real-time flood warning and forecasting system that will show precisely which areas are in danger of flooding during an event."

Mapping for the future

"The public really needs this information, and the quicker we get it done, the more money we can save," said Geodetic Survey's Gary Thompson.

With that in mind, North Carolina has set forth an aggressive schedule. The $23-million first phase will continue through 2002 and cover six major river basins. Eleven more basins will be mapped in two subsequent phases, which take the mapping progressively farther inland toward the mountains.

The North Carolina project may be the first, but it isn't likely to be the last floodplain mapping project conducted by an individual state. Several others have already petitioned FEMA for CTP status so they can kick off their own mapping programs.

In the meantime, state and federal officials across the United States are watching North Carolina as it sets new standards for floodplain mapping and making flood information accessible to the public.

Manufacturers/partners

Greenhorne & O'Mara (www.g-and-o.com) is the prime contractor for the floodplain mapping project, and **3Di's** EagleScan Division of Boulder, Colorado (www.3dillc.com) is the subcontractor handling LIDAR acquisition. **McKim & Creed Engineers** (www.mckimcreed.com) and **Hobbs, Upchurch & Associates** (www.hobbsupchurch.com) completed the field surveys during LIDAR collection. **PBS&J** (www.pbsj.com) and **ATCS** (Dulles, Virginia) are performing the hydraulic and hydrologic modeling. **SAIC** (www.saic.com) provides information technology support, and **SM&E, Inc.** (www.smeinc.com) is conducting geotechnical certifications. ◉